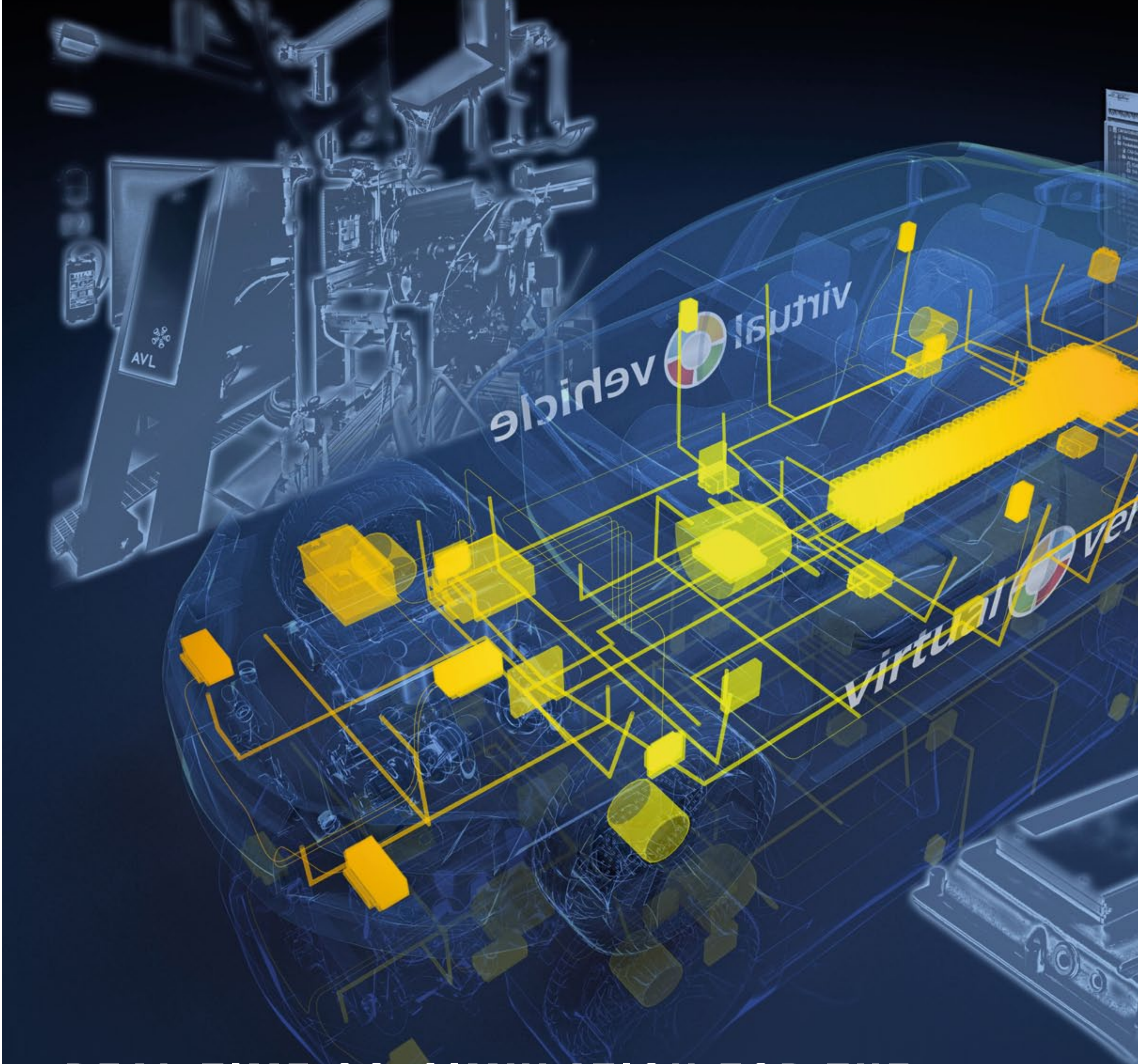

REAL-TIME CO-SIMULATION FOR THE CONTROL OF AN ENGINE TEST BENCH

The co-simulation of dynamic systems allows early predictions and design decisions concerning a product. A straightforward extension of the co-simulation approach is the integration of real-time systems into the system simulation. Within the research project Acorta the project partners Virtual Vehicle, AVL, Porsche and Universität Klagenfurt worked out innovative solutions for the coupling of real-time systems or real-time with non-real-time systems.

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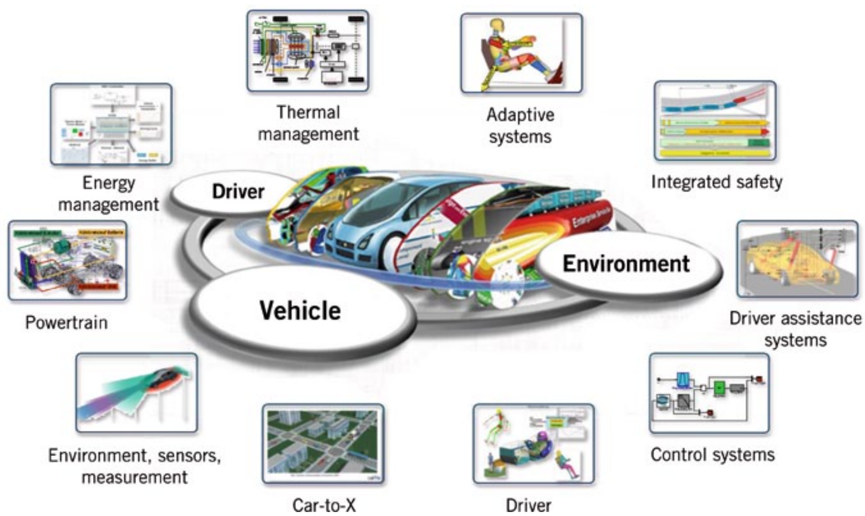
CO-SIMULATION AND REAL-TIME CO-SIMULATION

The complexity of vehicle development is driven by different factors: a high number of product variants, alternative fuels, driver assistance systems, Car-to-X communication, legislation, vehicle safety, etc. The term “system simulation” refers to an approach in which the complexity of the overall mechatronic product “vehicle” is mapped with its surroundings in a virtual development environment, where one or more components are connected to an interactive simulation model, ❶. The co-simulation approach allows that the participating departments (domains) can use their most suitable simulation tools for modelling the subsystems. Furthermore the reusability of subsystems is supported. Concerning co-simulation several problems have to be solved: integration of simulation tools, accurate data exchange, coupling of systems with different dynamic behaviour, and guarantee of the accuracy of the simulation [5].

A straightforward extension of the (non-real-time) co-simulation approach is the integration of real-time systems into the system simulation. In this case one or more components, which are available as real hardware, are directly integrated into the existing system model. In this consistent approach, the offline simulation models, typically with a high level of detail, test scenarios or environment simulations can be used with the real test equipment without the necessity of model conversion and/or code generation. With the extension of the co-simulation into the real-time level additional challenges remain: The coupling of the involved systems has to be time correct; round-trip-times must be kept as small as possible in order to ensure the stability of existing control loops; noisy sensor signals must be taken into account [1].

Basically, a distinction between real-time and non-real-time systems is useful for the following. Real-time systems (RT) satisfy the so-called hard real-time requirements (for example guaranteed response-time, deterministic runtime behaviour). Non-real-time systems (non-RT) do not satisfy these conditions in general, but may be executed faster than real-time (quasi real-time systems). ❷ shows an overview of the possible levels



❶ Interactive system simulation model for connecting different components and domains

of interaction between real-time and non-real-time co-simulation.

In the upper area of ② the offline simulation tools are coupled via the Icos co-simulation platform (http://www.v2c2.at/icos) from Virtual Vehicle. Each system has to run at least faster than in real-time (quasi real-time). The lower area of ② represents the coupling of real-time systems or real-time applications within a real-time system. Both levels are connected with special coupling and error correction methods, such that the resulting overall system complies with the requirements of hard real-time.

The main problem concerning real-time co-simulation is the latency occurring in the closed loop due to finite communication-, computation- or data-processing-times. From a control point of view these dead-times cause considerable problems in the regulation and control of subsystems, which can lead to oscillations and in particular to a distorted picture of the real system as a whole.

ACORTA APPROACH

In the development process the described direct coupling of co-simulation models and real-time systems is currently not possible in the development process. The research project “Advanced Co-Simulation Methods for Real-Time Applications” (Acorta, http://www.acorta.info) at the Virtual Vehicle Research Center, together with the industrial partners AVL List GmbH and Dr. Ing. h.c. F. Porsche AG and the academic partner Alpen-Adria-Universität Klagenfurt, tries to close this gap. The core of the project is the development of a new coupling algorithm to fulfil all the necessary requirements of real-time co-simulation. The developed methodology is reviewed in several use cases for the involved industry partners.

COUPLING METHODOLOGY

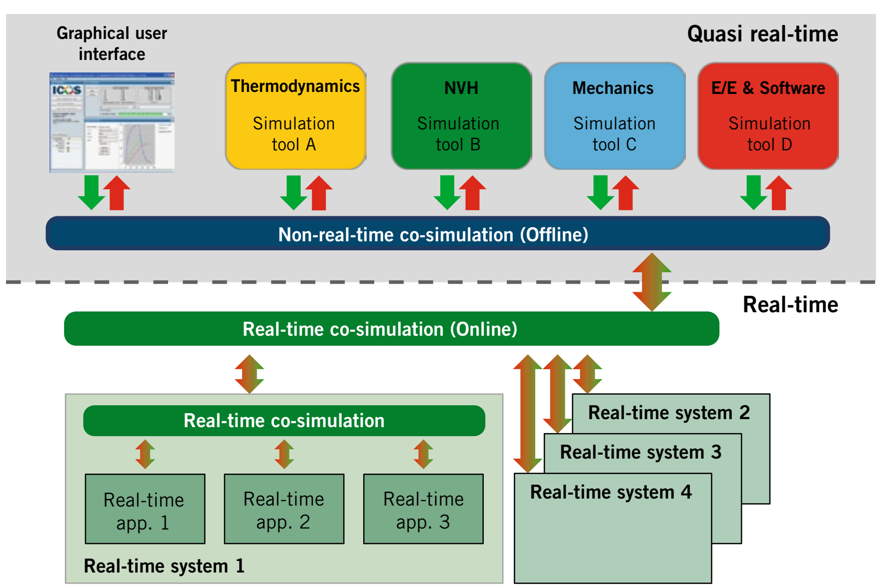
Modern co-simulation platforms, such as Icos from Virtual Vehicle, are using signal-based coupling algorithms to ensure a correct data exchange between the involved sub-models [5]. To ensure a correct co-simulation so-called coupling elements, which are typically based on polynomial extrapolation techniques of low order together with additional error correction methods, such as NEPCE [2], are inserted at critical points in the system simulation.

Applying the coupling element in the forward and backward branch of a closed-loop system results in a break-up of the loop. Due to the improved extrapolation and error compensation in the signal path a reduction of the overall latency occurs. Therefore an improvement of the closed-loop dynamics of the system is possible. This will be illustrated in an example using the control of an engine test bench.

USE CASE AT PORSCHE

The target of this use case is to increase the model quality for the virtual parameterisation of engine control units on a combustion engine hardware-in-the-loop (HiL) test bench by an integration of available off-line simulation tools. A direct embedding of the offline available simulation tools on a real-time platform is often not possible. Therefore a real-time oriented co-simulation by means of a decentralised connection of these tools leads to the only solution.

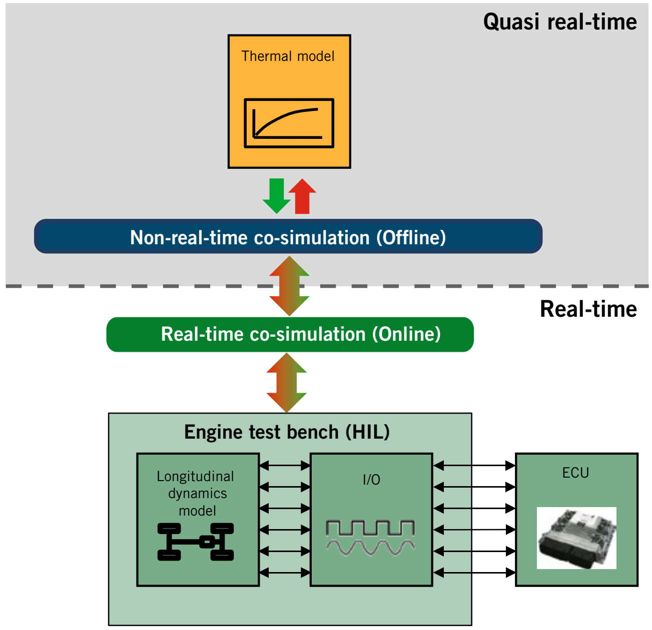
❸ shows the use case where a thermal simulation model is connected via co-simulation to a real engine control unit. Thus, for example, the parameterisation of the control circuit for the engine tem-



❷ Levels of interaction between real-time and non-real-time components perature can be performed already on a HiL test bench [4, 6].

USE CASE AT AVL

Another test bench use case at AVL applies the coupling of real-time applications as well as the coupling of real-time systems and offline co-simulation to the real-time system Arte.Lab. This is shown in ❹.



❸ Structure and use case of the combustion engine HiL test bench at Porsche

CONTROL ON THE ENGINE TEST BENCH

Here, the developed method shall be presented with the example of a control for the output machine of an engine test bench. ❺ presents the structure of the test bench. The target of the control is to let the dyno-speed follow a desired speed. The real-time control of the output machine [3] as well as the coupling element are executed on the real-time system Arte.Lab with the underlying real-time operating system Intime. The latency in the system leads to an increased tendency to oscillations in the control loop and restricts the available system dynamics.

RESULTS

For further investigations, the control circuit is driven by a rectangular reference signal (nominal speed steps). ❻ shows two different phases of the test run:

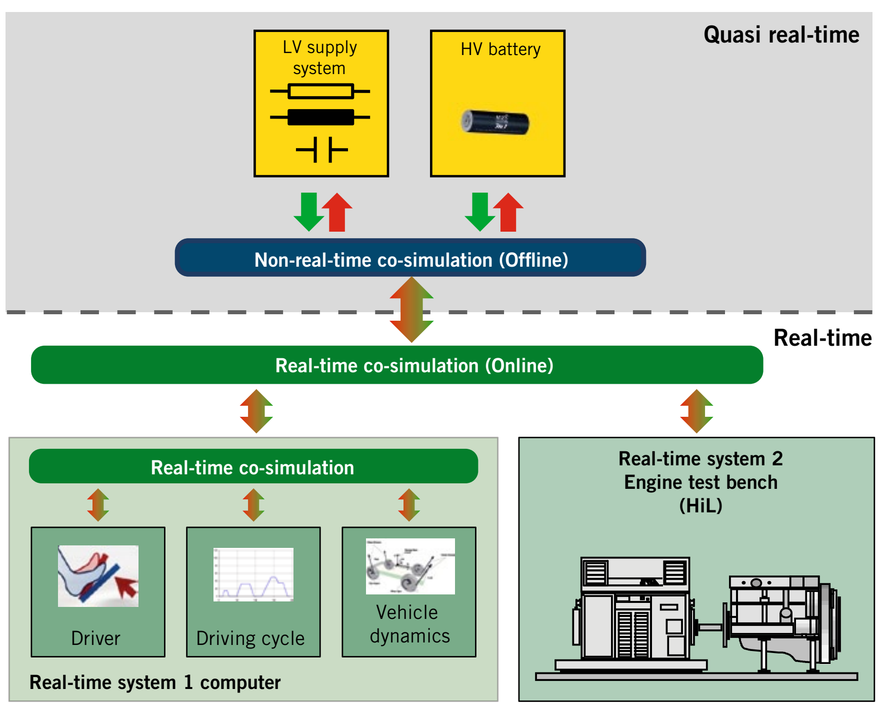
- No Acorta coupling: This part serves as a reference and shows a clear overshoot of the dyno-speed.
- Signal-based Acorta coupling: The signal-based coupling techniques lead to a reduction of the overshoot for the dyno-speed due to the compensation of the round-trip times.

The Acorta approach enables the approximate compensation of system occurring latencies for the first time in real-time. Using the proposed method, the effective bandwidth of the control-loop can be significantly increased (a factor of two for this setup). This results in a control-loop with higher dynamics, which could not be achieved without the compensation scheme.

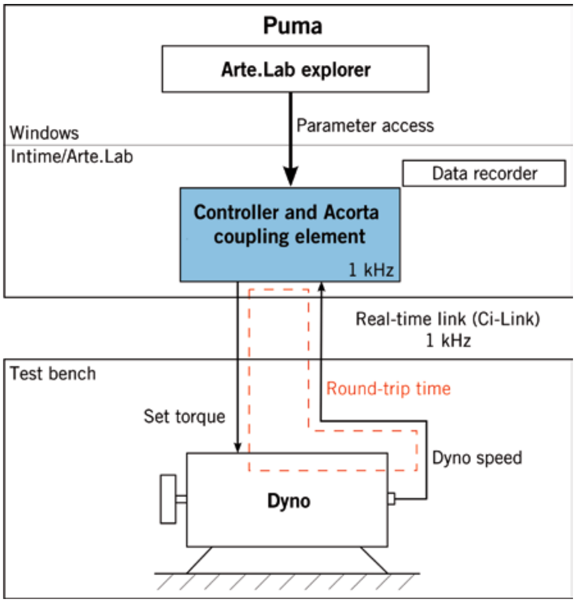
CONCLUSION AND OUTLOOK

The setup of future modern test systems will be supported by the coupling methods developed in the research project Acorta. Additionally distributed control systems, as they arise through the use of ECU networks or multi-core processor applications in the real vehicle, can be improved using the real-time co-simulation. Bugs can be prohibited or compensated. As illustrated in an example with the control of an output machine of an engine test bench the applicable dynamic range of a dyno-control could be increased by compensating the occurring latencies in the closed-loop with the presented coupling element.

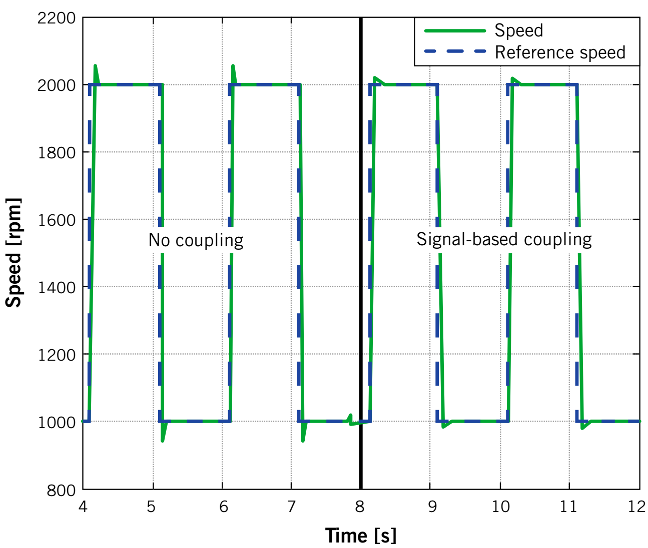
The current work in the project focuses on the integration of model-based coupling methods in the Acorta approach. These methods are using additional information in the form of locally



❹ Structure and use case of the test bench at AVL



❺ Structure of the engine test bench with the included Acorta coupling element



❻ Comparison of measurement results with and without Acorta coupling – clear overshoot of the dyno-speed if there is no coupling (peaks in green)

valid sub-models in order to enable a more accurate extrapolation and the handling of noisy sensor signals. Promising results could already been shown in first tests and will be published in the near future. The coupling of a non-real-time co-simulation has also been tested successfully on a first prototype.

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